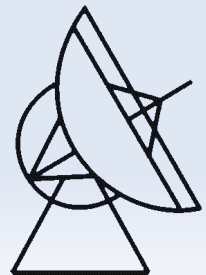
The PALFA Survey:

Going to great depths to find radio pulsars

Patrick Lazarus
MPIfR

for the
PALFA Collaboration

(IAU Symposium 291 – Aug. 20, 2012)



The Team

~30 PALFA members:

B. Allen, N. D. R. Bhat, S. Bogdanov, A. Bouchard, A. Brazier, F. Camilo, F. Cardoso, S. Chatterjee, J. M. Cordes, F. Crawford, J. S. Deneva, G. Desvignes, P. C. C. Freire, J. W. T. Hessels, F. A. Jenet, V. M. Kaspi, B. Knispel, P. Lazarus, J. van Leeuwen, D. R. Lorimer, R. Lynch, A. G. Lyne, M. A. McLaughlin, D. J. Nice, S. M. Ransom, P. Scholz, X. Siemens, I. H. Stairs, B. W. Stappers, K. Stovall, J. Swiggum, A. Venkataraman, W. Zhu

PALFA Membership

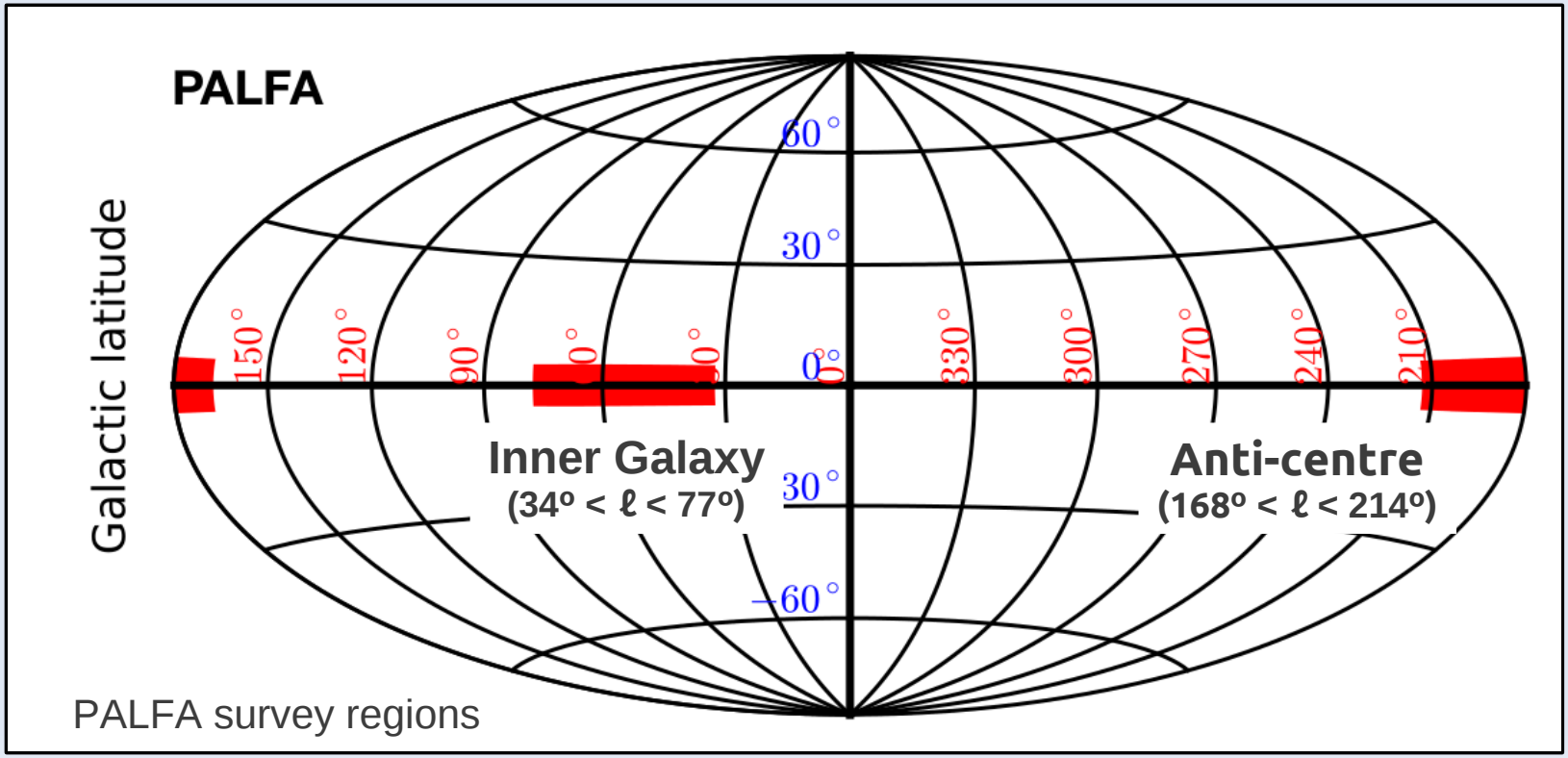
The Pulsar-ALFA Survey at a Glance

- PALFA survey is searching the Galactic Plane for radio pulsars
  - Started in 2004
- Arecibo Observatory
  - 305-m single dish
  - Transit telescope

Arecibo Observatory (www.naic.edu)

The Pulsar-ALFA Survey at a Glance

- **Surveying Galactic plane**
  - **Two regions visible from AO**
  - **$|b| < 5°$**



PALFA survey regions

The Pulsar-ALFA Survey at a Glance

- **Using 7-beam ALFA receiver**
  - **Freq.: ~ 1.4 GHz (λ = 21 cm)**
  - **BW_{max}: ~320 MHz**
  - **Sample time: ~64 us**
  - **2-5 min integrations**

The ALFA Receiver (D. Smith, CSIRO)

The Pulsar-ALFA Survey at a Glance

- **Two backends**
  - **Wide-band Arecibo Pulsar Processors (WAPPs; 2004-2010)**

    BW = 100 MHz; 256 channels
  - **Mock spectrometers (2009-)**

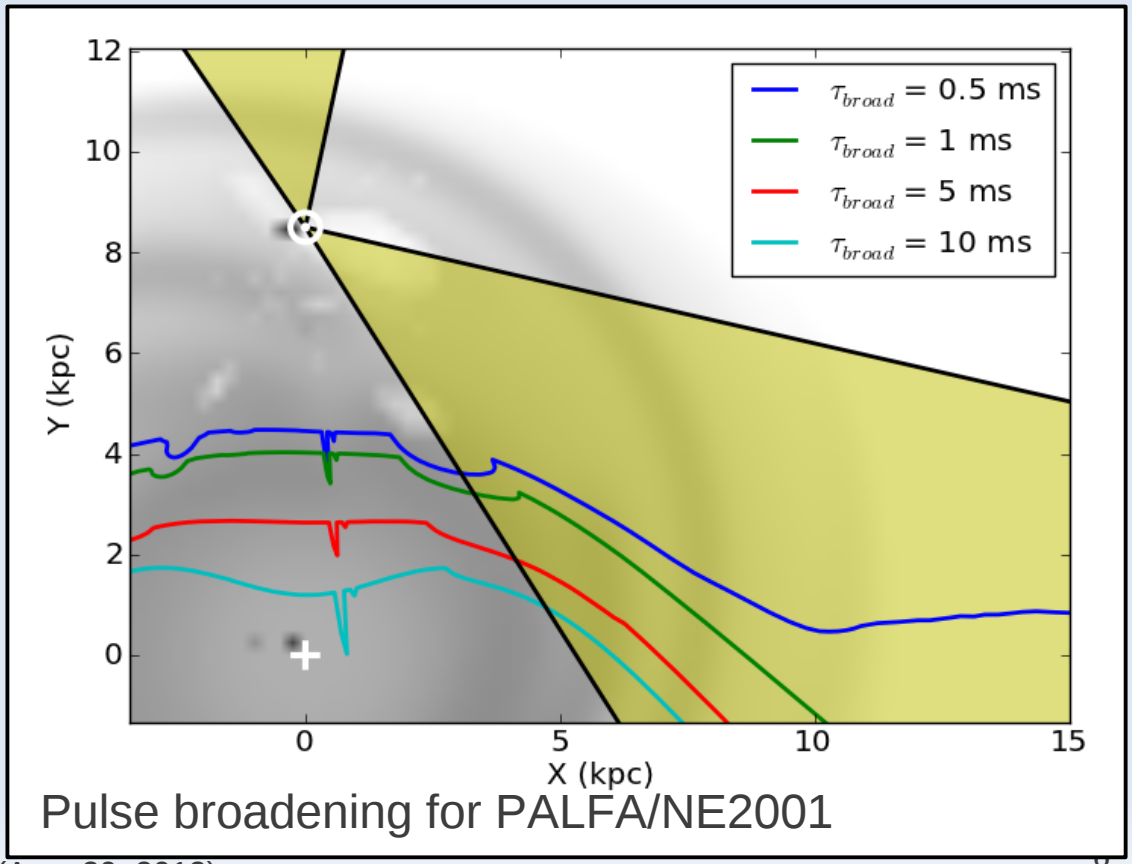
    BW = 320 MHz; 960 channels
  - **WAPPs/Mocks used in parallel in 2009**

Goals of the Survey

- **Expand known population of radio pulsars**
  - Better understanding of numbers/properties
- **Discover more transient pulsars**
  - Nullers, RRATs, magnetars, etc.
- **Find millisecond pulsars (MSPs)**
  - For PTAs, tests of gravity, EoS, etc.
- **Young pulsars, PSR/BH binary, and more...**

PALFA: Key characteristics

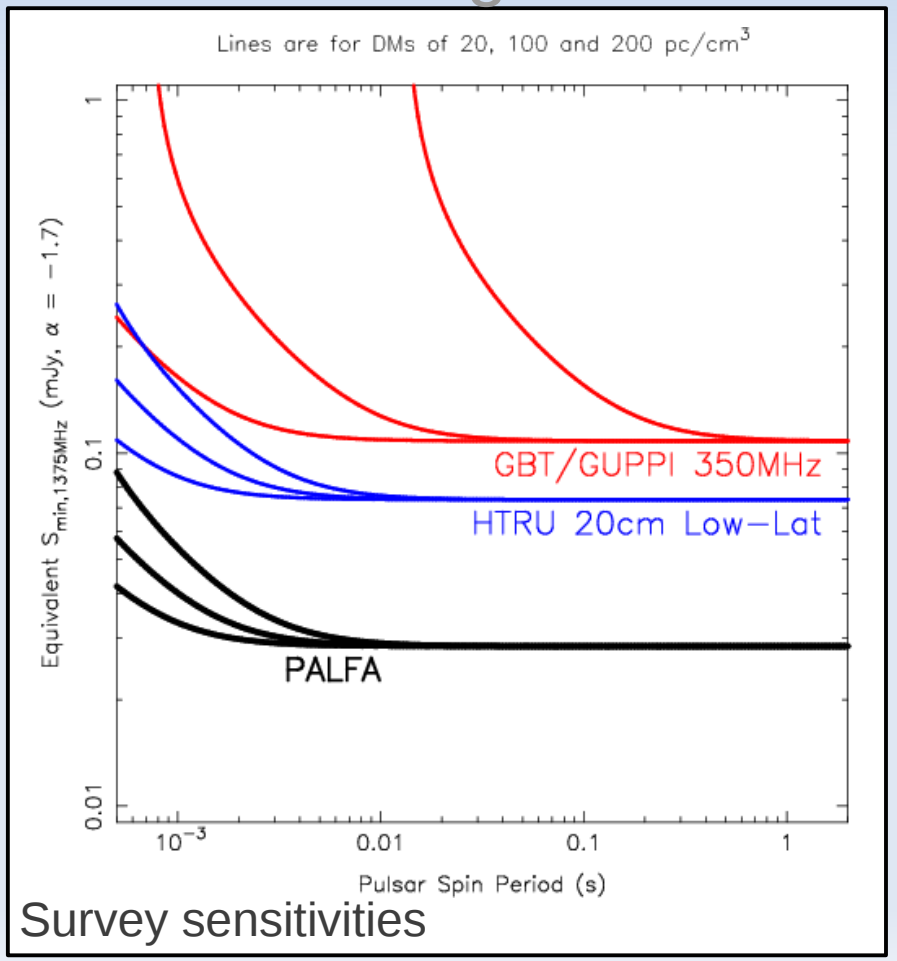
- **High time/freq. resolution**
  - **Depth is not limited by dispersive smearing (scattering still limits depth for fastest MSPs)**



Pulse broadening for PALFA/NE2001

PALFA: Key characteristics

- High time/freq. resolution
  - Depth is not limited by dispersive smearing (scattering still limits depth)
- **Large collecting area**
  - **The most sensitive large-scale survey**



Survey sensitivities

PALFA: Key characteristics

- High time/freq. resolution
  - Depth is not limited by dispersive smearing (scattering still limits depth)
- Large collecting area
  - The most sensitive large-scale survey
- **Short integrations**
  - **More manageable data** (*only* 500 TB expected)
  - **Easier to be sensitive to binary pulsars**

Pipelines and Processing

- **Two complementary pipelines:**

	PRESTO	Einstein@Home
Analysis time	5 days	(1 month)
Acceleration search technique	Constant accel (Fourier domain)	6662 templates (Time domain)
Min. P-orb.	~ 1 hr	~ 11min

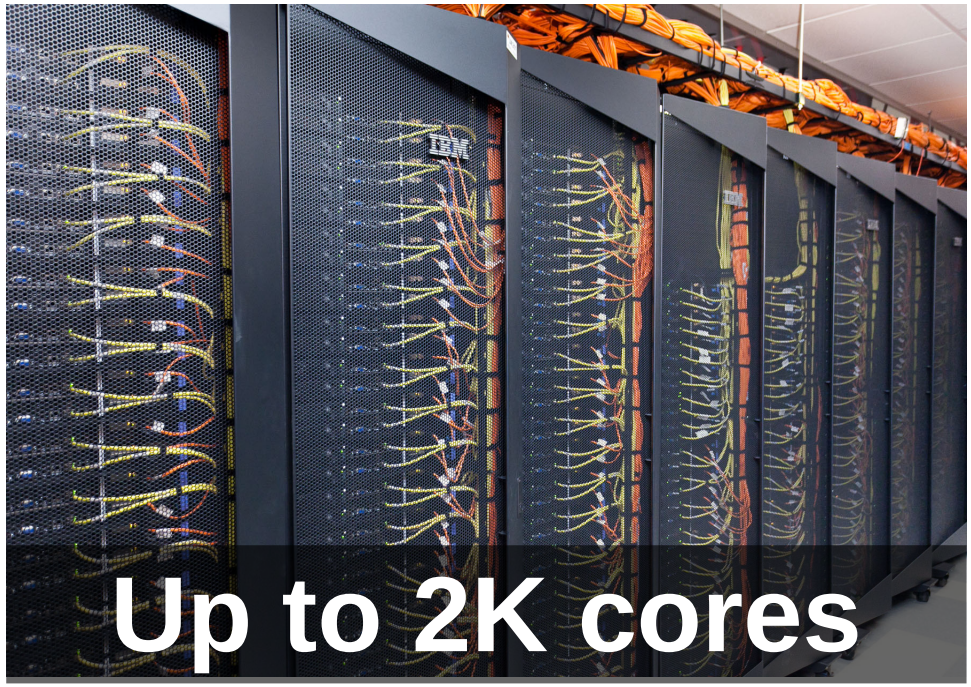
Different strategies for:

- **Radio interference removal**
- **Candidate sifting and viewing**

Pipelines and Processing

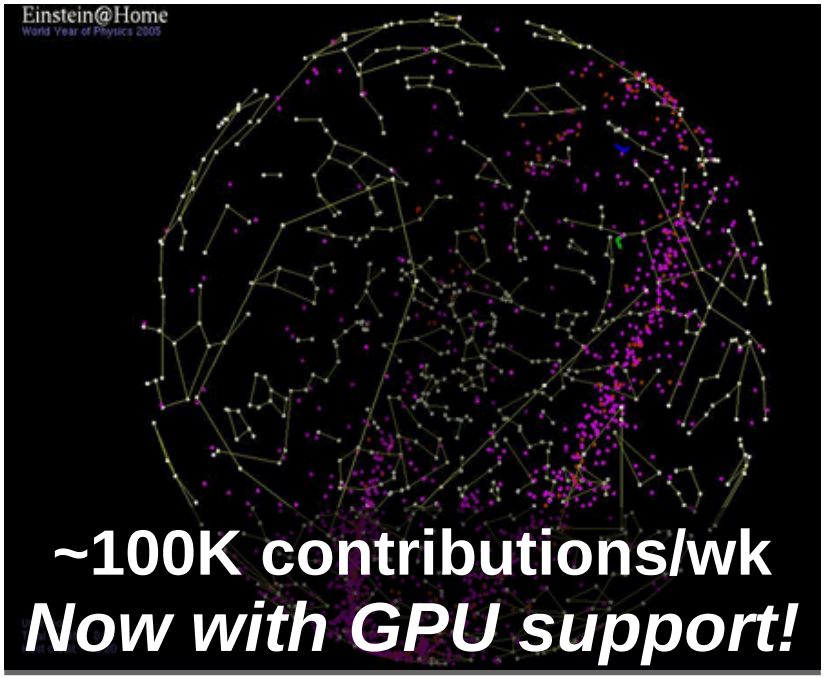
- **Utilizing new (super-)computing resources**

PRESTO



The "GUILLIMIN" super computer (McGill)

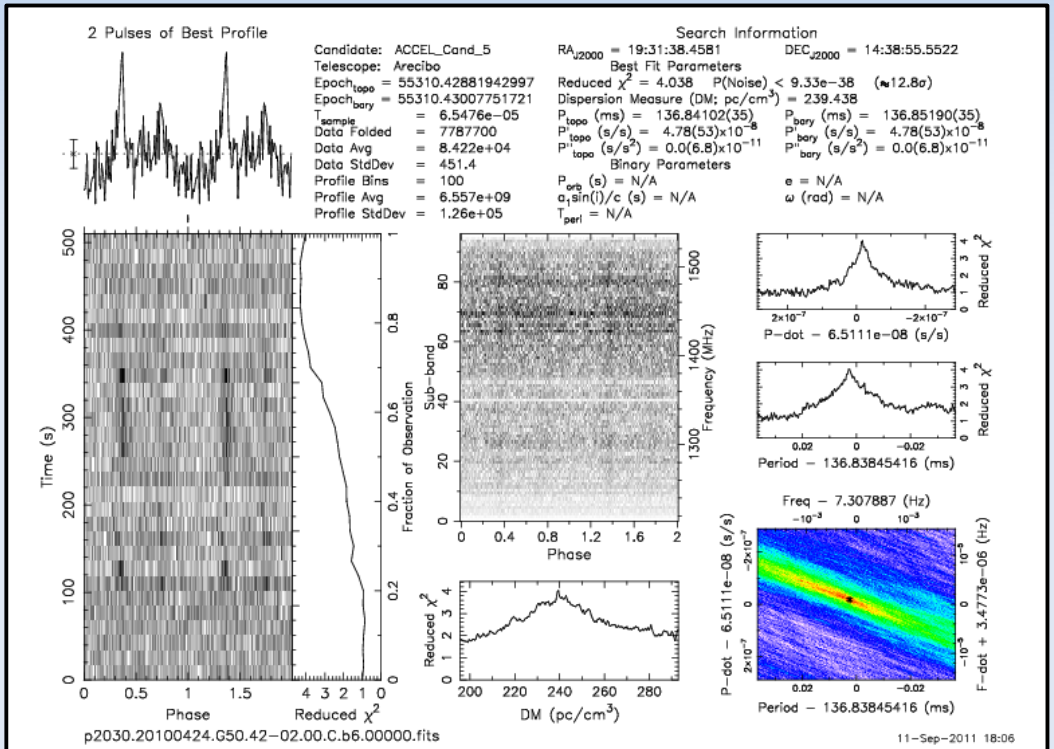
Einstein@Home



E@H running (http://einstein.phys.uwm.edu/)

Candidates and Viewing

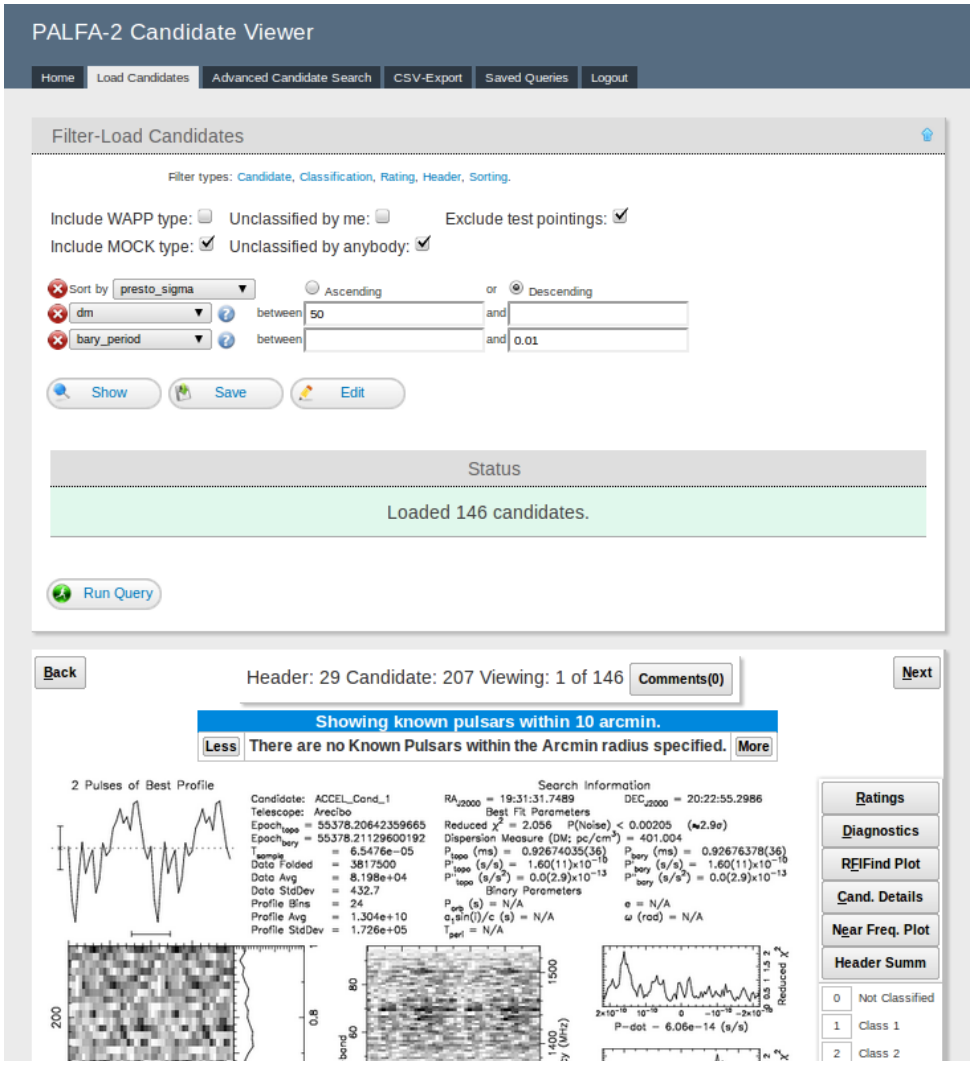
- **> 5M candidates and counting**



PRESTO diagnostic plot. We have millions of these!

Candidates and Viewing

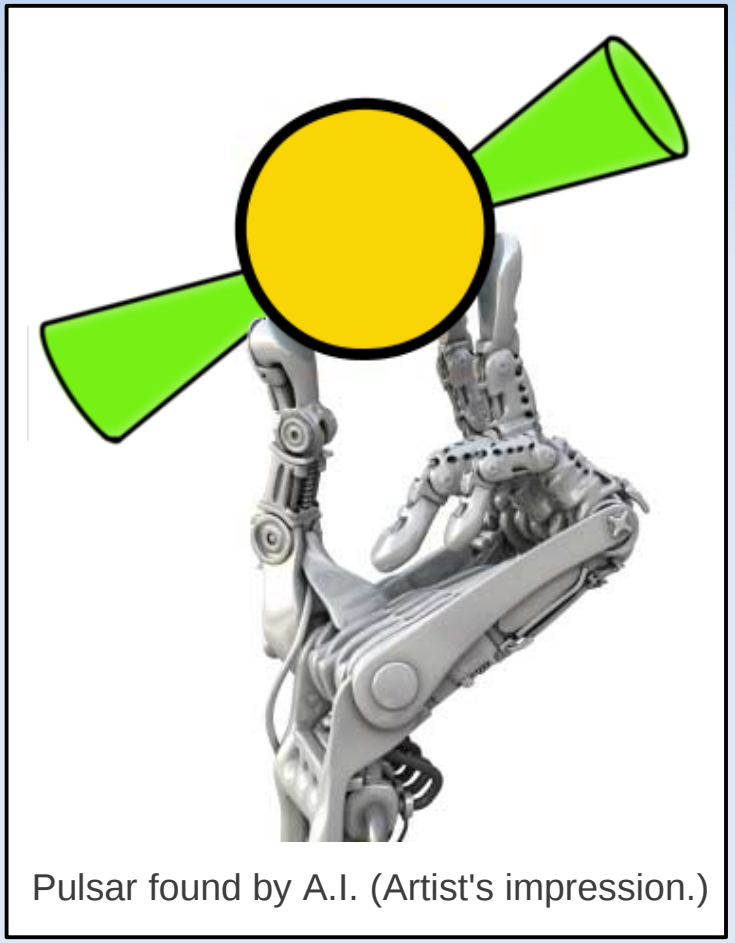
- > 5M candidates and counting
- **Looking through them with:**
  - **Online viewer (www.cyberska.org)**



Online PALFA candidate viewer app (cyberska.org)

Candidates and Viewing

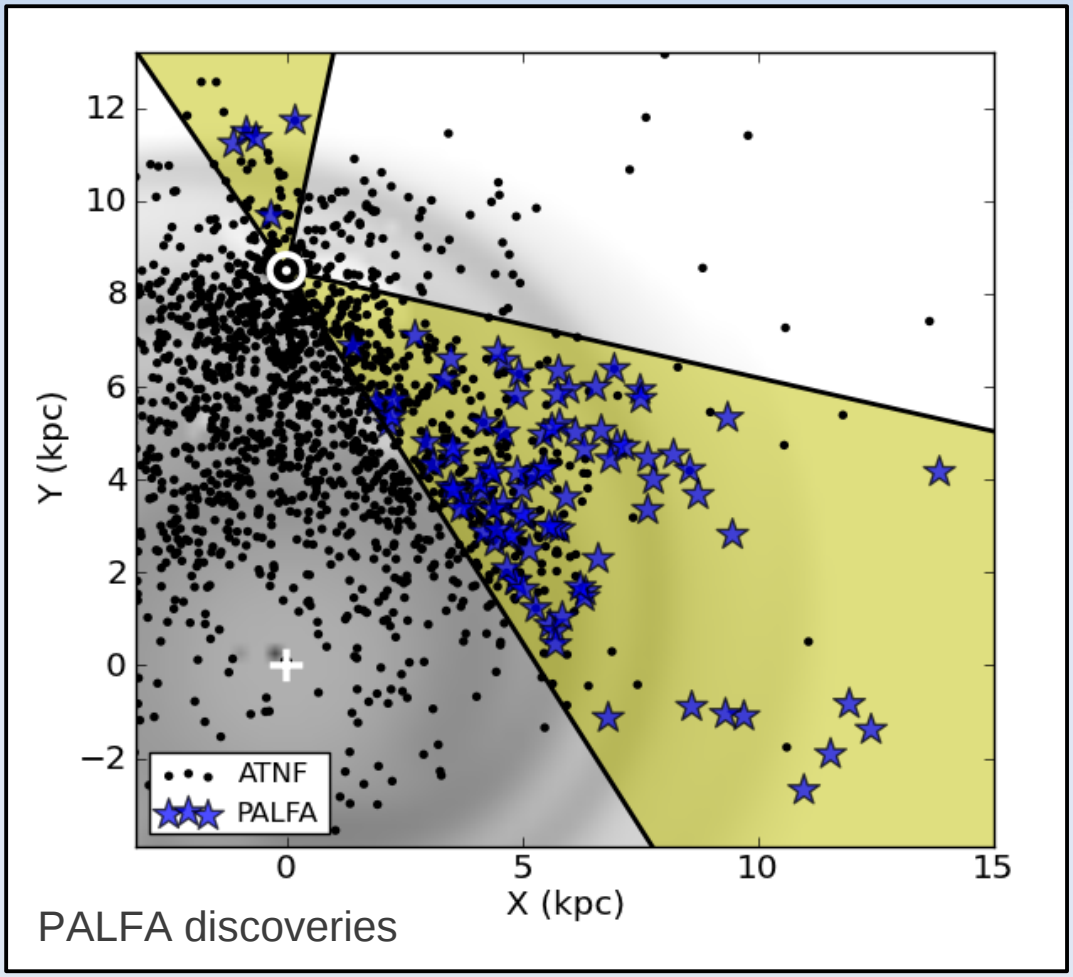
- > 5M candidates and counting
- **Looking through them with:**
  - On-line viewer
  - **Scoring heuristics** (similar to Keith, et al., 2009)
  - **Artificial Intelligence(s)** (similar to Eatough, et al., 2010)



Pulsar found by A.I. (Artist's impression.)

Results

- **100 pulsars discovered**



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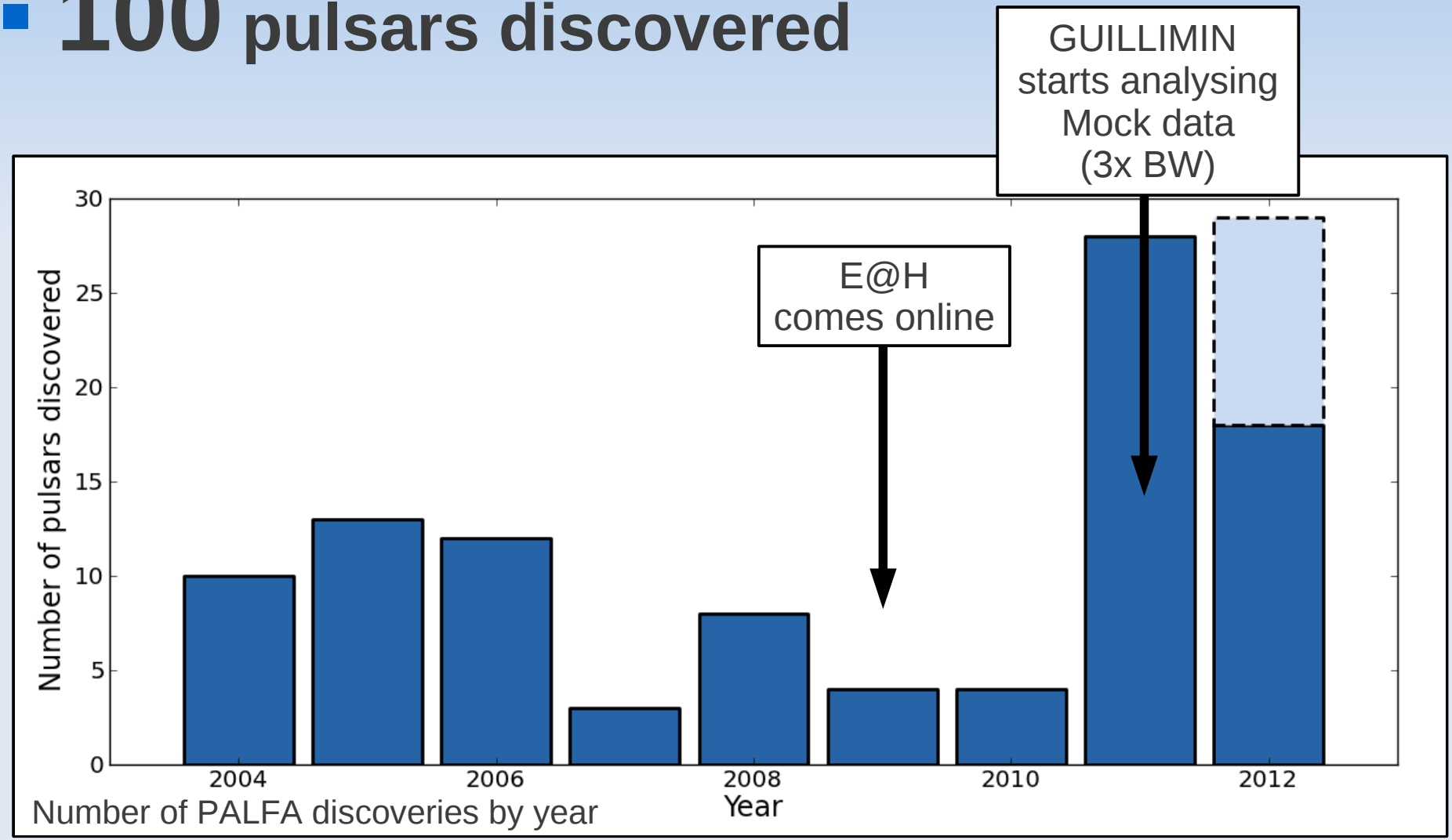


WAPP vs. Mock

- In 2009, PALFA started using the Mocks
  - BW = 320 MHz
    (receiver's full band; ~3x more than WAPPs)
  - Better resiliency to RFI
- WAPPs:
  - 56 discoveries in ~164 sq. deg.
    (1 PSR / 2.9 sq. deg.)
- Mocks:
  - 44 discoveries in ~70 sq. deg.
    (1 PSR / 1.6 sq. deg.)

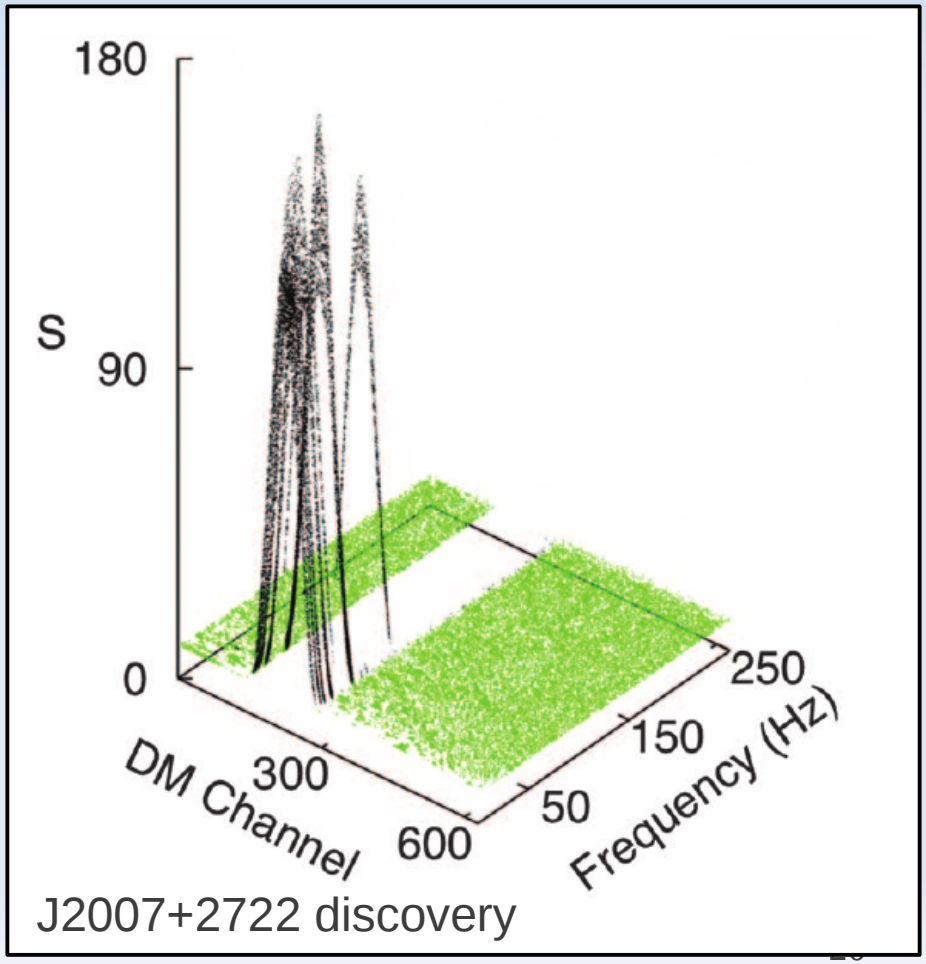
Highlights I

- **J1906+0746** (P=144ms; DM=212)
  - The youngest (112 kyr) relativisitic binary pulsar.
    (Lorimer, et al., 2006; Kasian, 2012; van Leeuwen, et al., *in prep*)
- **J1903+0327** (P=2.15ms; DM=298)
  - Eccentric MSP. Formed in triple system.
    (Champion et al., 2008; Freire et al., 2011)
- **J1856+0245** (P=80.9ms; DM=650)
  - Young (27 kyr) pulsar coincident with HESS source.
    (Hessels et al., 2008)
- **7 RRATs**

  (Deneva et al., 2009)

Highlights II

- **J2007+2722** (P=24.5 ms; DM=127 pc cm^{-3})
  - First pulsar discovered by Einstein@Home (Knispel et al., 2010, *Science*)
- **23 Einstein@Home discoveries**
  - 4 MSPs
  - 3 binary pulsars



J2007+2722 discovery

Recent Results I

Timing of 2 MSPs (Deneva et al., accepted, *ApJ*)

- **J1949+3106**
  - P = 13.14 ms, DM = 164 pc cm^{-3}
  - σ_{RMS}=3.96 μs
- **J1955+2527**
  - P = 4.87 ms, DM = 210 pc cm^{-3}
  - σ_{RMS}=11.14 μs

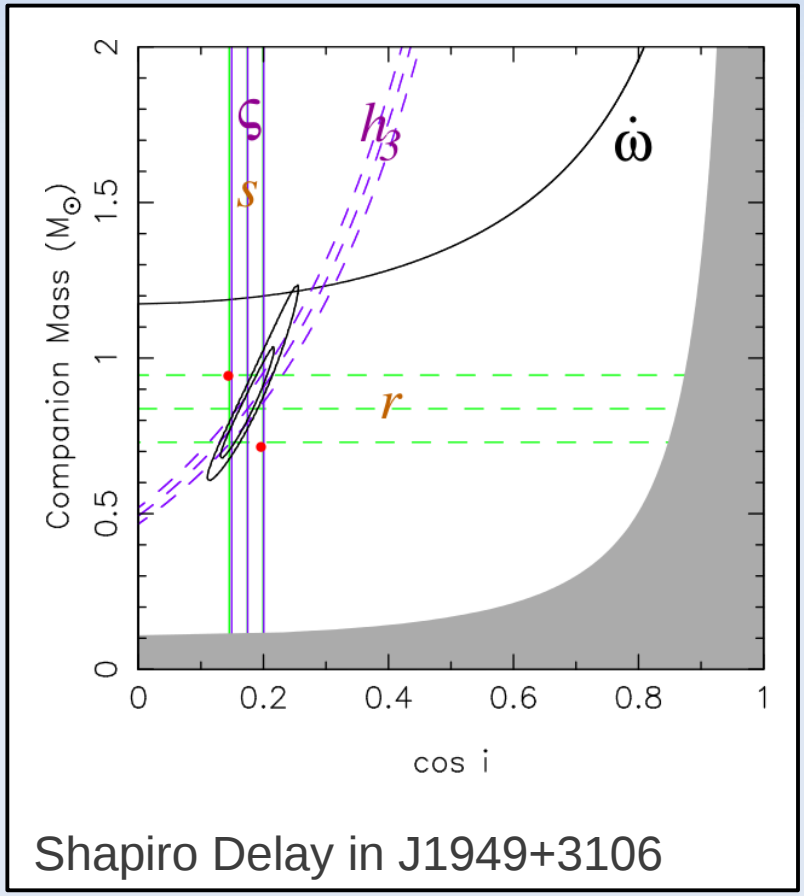
Recent Results I

Timing of 2 MSPs, incl. mass measurement (Deneva et al., accepted, *ApJ*)

- **J1949+3106:**

  1.95-day binary orbit

$$M_p = 1.47^{+0.43}_{-0.31}\ M_{sun}$$
$$M_c = 0.85^{+0.14}_{-0.11}\ M_{sun}$$
$$\dot{\omega} < 0.02\ deg/yr$$

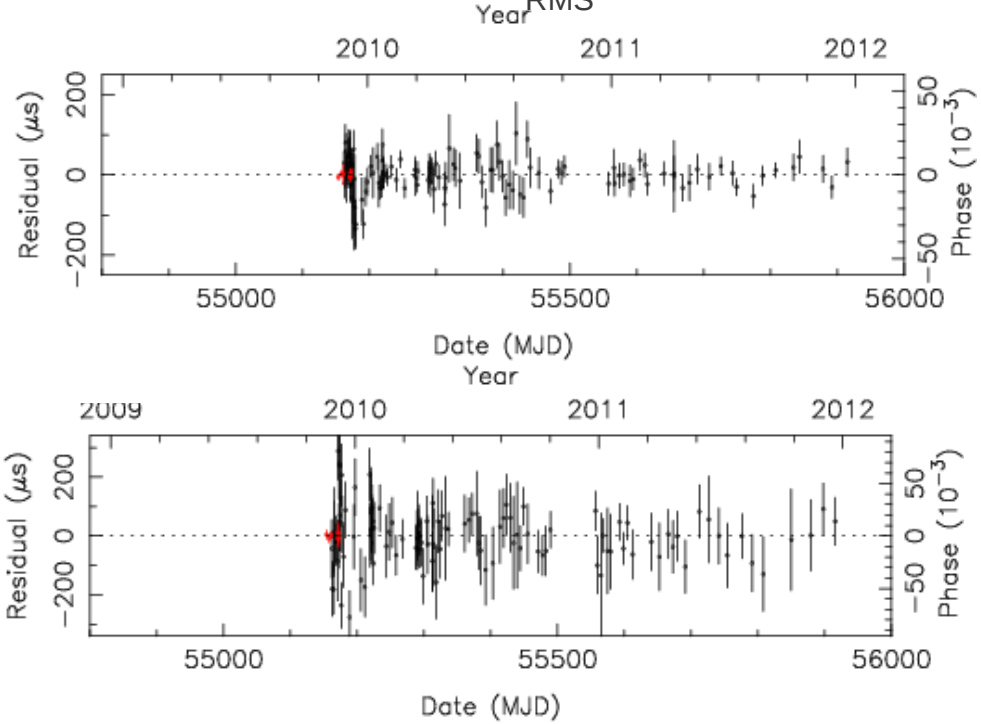


Shapiro Delay in J1949+3106

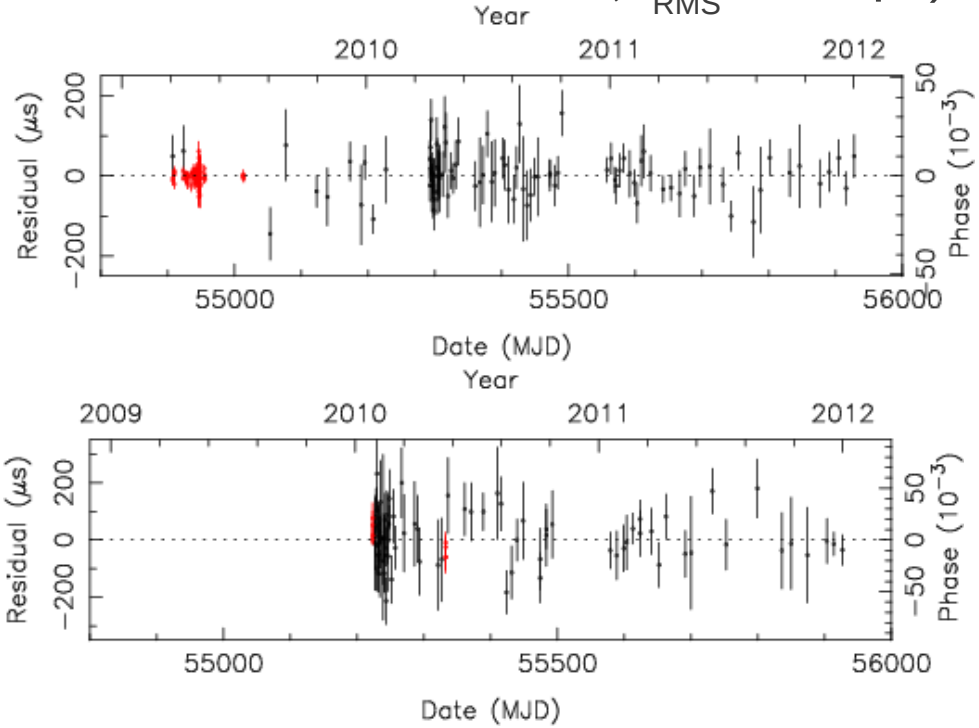
Recent Results II

Timing of 4 MSPs (Crawford et al., accepted, *ApJ*):

J1844+0115 (σ_{RMS}=25.4 μs)



J1900+0308 (σ_{RMS}=15.8 μs)



J1850+0124 (σ_{RMS}=51.6 μs)

J1944+2236 (σ_{RMS}=66.1 μs)

Finding MSPs

- **PALFA discovered MSPs (P < 30 ms)**
  - **17 MSPs discovered, so far**

- **J0557+01** (P=2.55 ms; DM=103)
- **J1844+0115** (P=4.19 ms; DM=148)
- **J1850+0124** (P=3.56 ms; DM=119)
- **J1900+0308** (P=4.91 ms; DM=250)
- **J1902+03** (P=7.79 ms; DM=254)
- **J1903+0327** (P=2.15 ms; DM=298)
- **J1905+04** (P=6.09 ms; DM=183)
- **J1906+01** (P=2.79 ms; DM=127)
- **J1913+11** (P=27.3 ms; DM 341)
- **J1914+07** (P=18.51ms; DM=225)
- **J1944+22** (P=3.62 ms; DM=184)
- **J1949+3106** (P=13.14 ms; DM=164)
- **J1950+24** (P=4.30 ms; DM=142)
- **J1952+2630** (P=20.73 ms; DM=315)
- **J1955+25** (P=4.87 ms; DM=210)
- **J1957+25** (P=3.96 ms; DM=46)
- **J2007+2722** (P=24.50 ms; DM=127)

Finding MSPs

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Four PALFA MSPs with P < 10 ms and DM > 200

- J0557+01 (P=2.55 … =18.51ms; DM=225)
- J1844+0115 (P=4 … =3.62 ms; DM=184)
- J1850+0124 (P=3 … (P=13.14 ms; DM=164)
- **J1900+0308 (P=4.91 ms; DM=250)**
- **J1902+03 (P=7.79 ms; DM=254)**
- **J1903+0327 (P=2.15 ms; DM=298)**
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Finding MSPs

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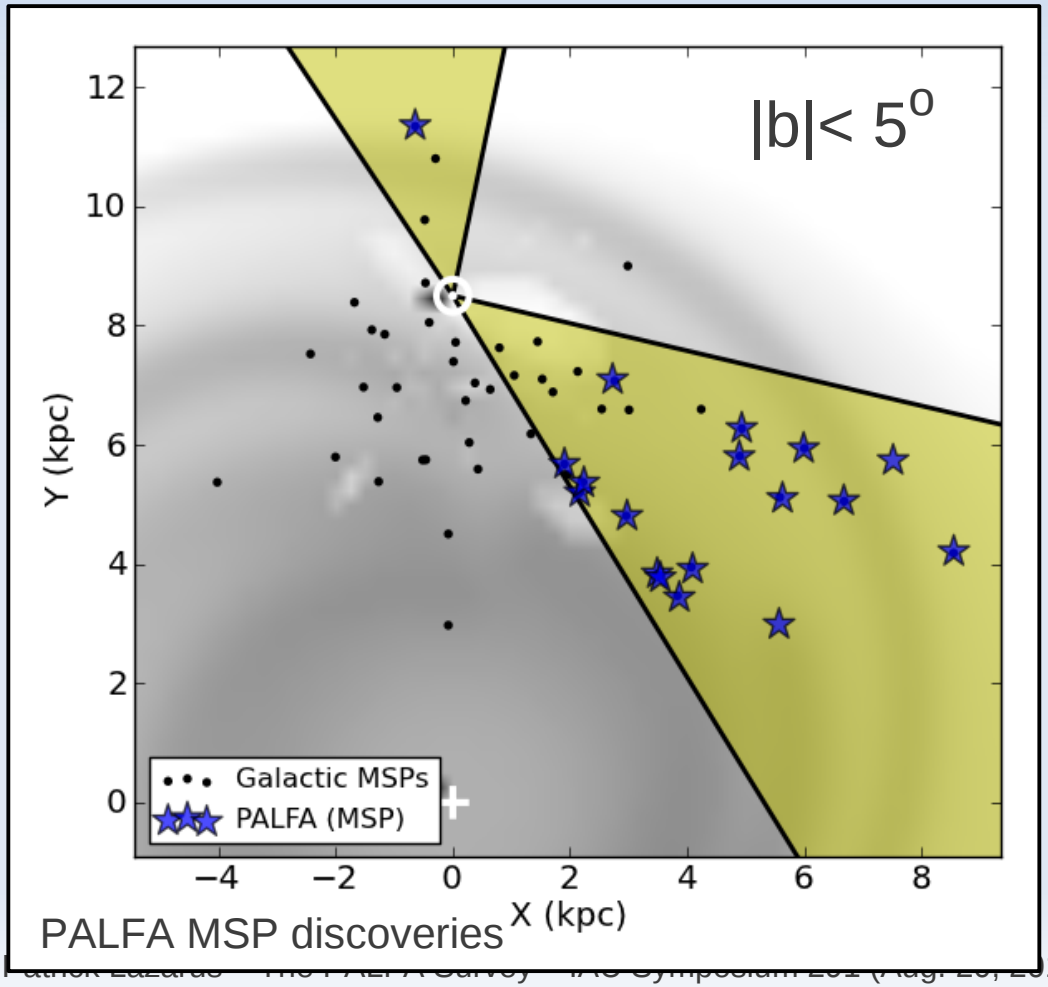
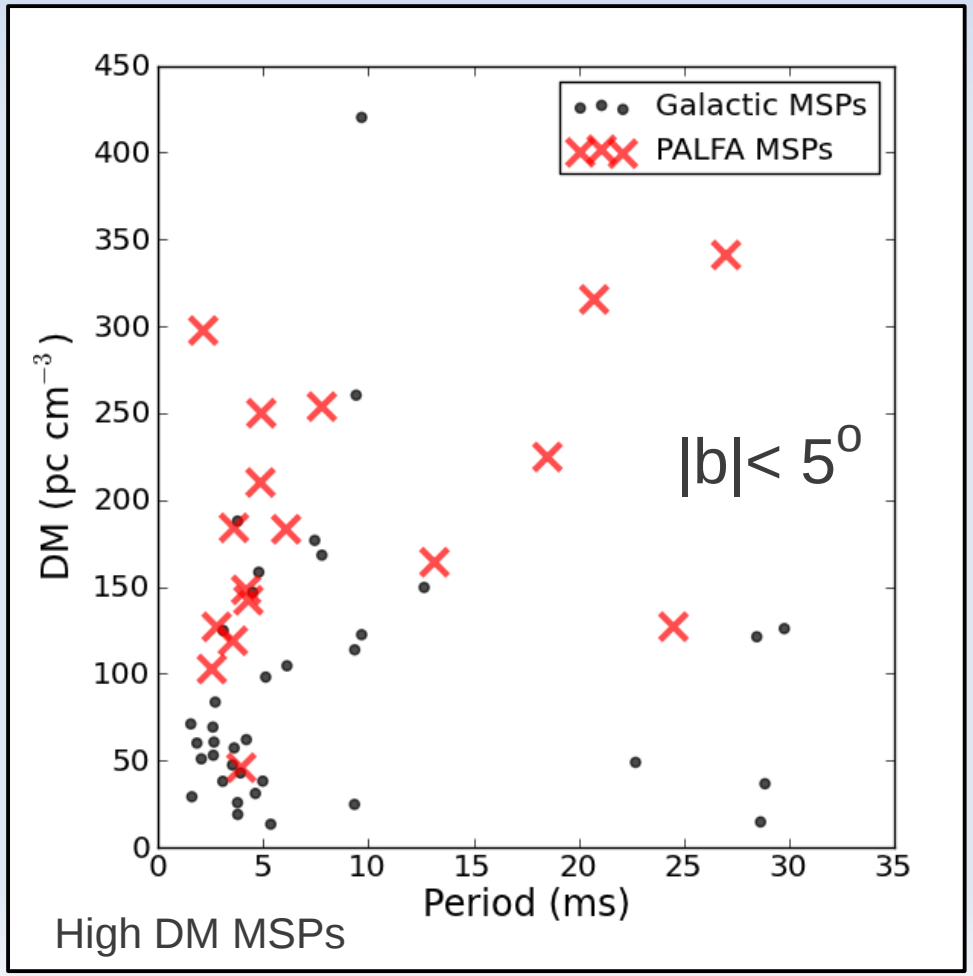


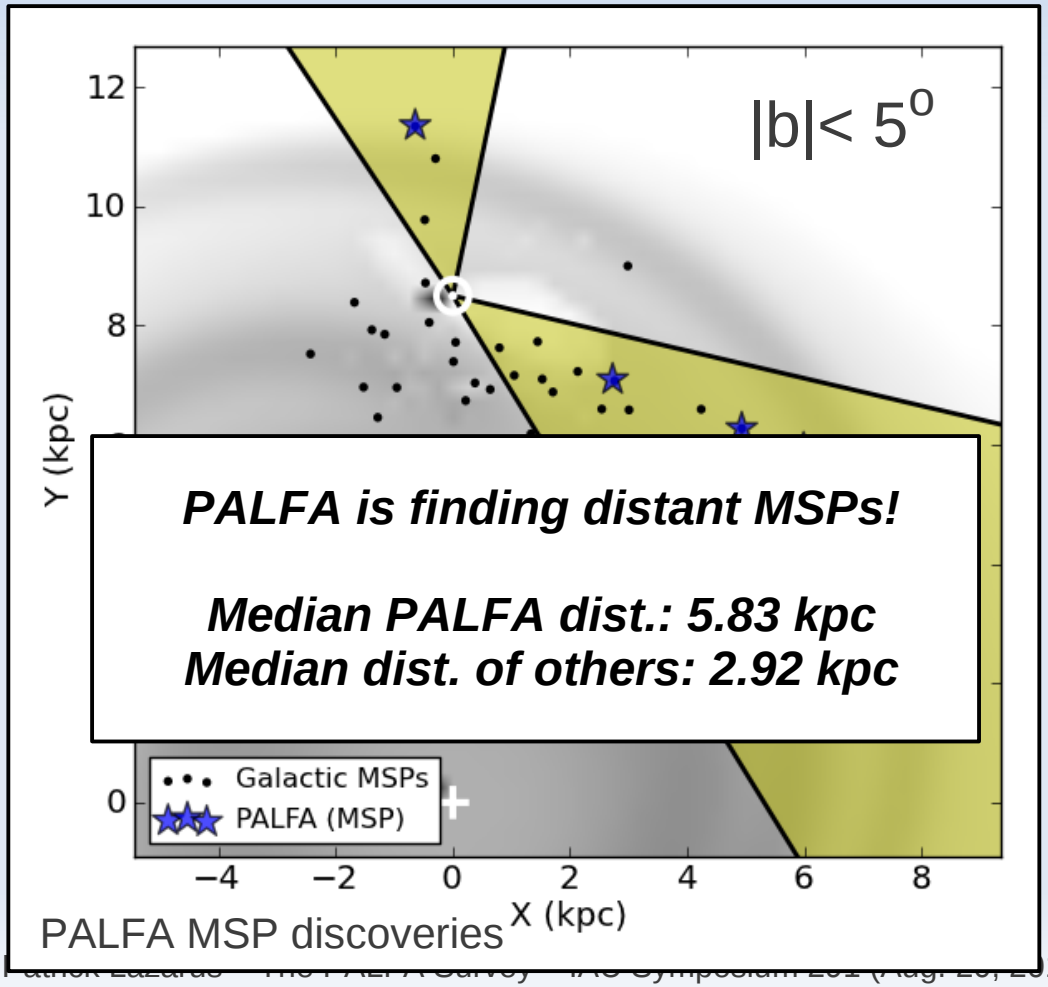
PALFA MSP discoveries



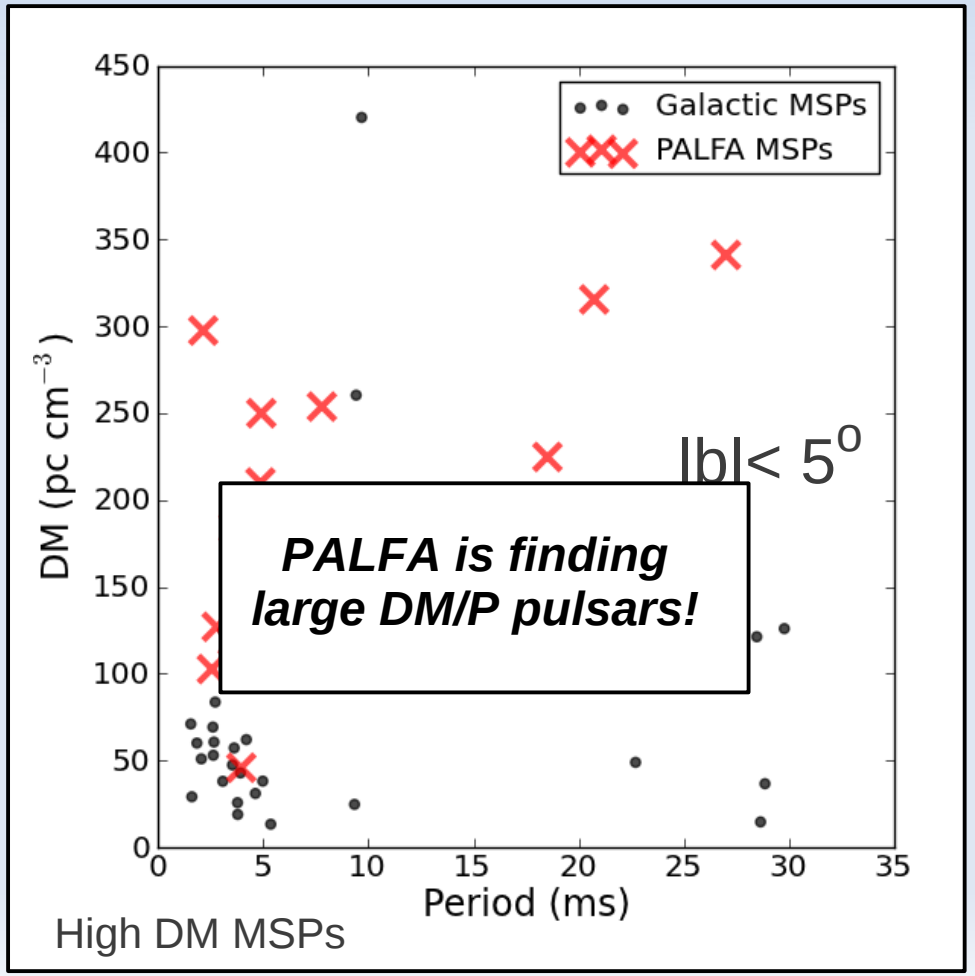
High DM MSPs

Finding MSPs

- **PALFA discovered MSPs (P < 30 ms)**
  - **17 MSPs discovered, so far**



PALFA MSP discoveries



High DM MSPs

PALFA is On-Going

- Still more observing
  - Only 10% done with superior set-up (i.e. Mocks)
- New pipeline being beta tested
  - Improved RFI identification and excision
- Re-analysis with new pipeline planned
- Continuing development of online tools (www.cyberska.org)
  - Streamlined work-flow/collaboration

Conclusions

- The PALFA survey is an ambitious project
  - Seaching Galactic plane with Arecibo
  - Pipelines running on new computing resources
  - Already many exciting discoveries
- Improving data analysis pipelines
- Going to greater Galactic depths to find pulsars
- 100 pulsars already discovered, and many more expected